Captain Salvatore Raineri
with the Author's Compliments

SOME EXPERIENCES

IN

NAVAL ARCHITECTURE:

BEING THE

INTRODUCTORY ADDRESS

AT THE

OPENING OF THE SIXTEENTH SESSION

OF THE

LIVERPOOL ENGINEERING SOCIETY,
2ND OCTOBER, 1889.

BY HENRY H. WEST, M. INST. C.E., &c., PRESIDENT.

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GENTLEMEN,

My first duty is to thank you for the honour you have done me in electing me to fill the Presidential Chair of our Society for the coming year. I appreciate this honour very highly.

I have too keen a sense of my own deficiencies to have any hope of attaining to the success with which the duties of the Chair have been performed by my predecessors; but I feel sure that, since it is by your suffrages I am placed in the honourable position of your President, I may rely with confidence on your loyal and cordial support; and I venture to hope that by your kind assistance I may at least impartially—if imperfectly—fulfil the trust which you have imposed upon me.

It will not be an inappropriate introduction to the few remarks which I shall have to make to you this evening if I briefly refer to what I know must be in the minds of many of us, as engineers deeply interested in the future honour and welfare of our profession.

Many of our Liverpool institutions bear witness to the fact that we have not lacked large-hearted citizens and neighbours, whose wealth has enabled them to give practical and generous expression to their good-will towards their fellow citizens.

Prominent among these is the name of Sir Andrew Barclay Walker, Bart. To him the city owes its Art Gallery; and now our

own profession has been specially singled out by him for the direct benefit of his generosity, in his munificent gift to Liverpool University College of a fully equipped Engineering Laboratory, to be opened in the course of a very few days. This laboratory, in its buildings and in its appliances, is being completed, I may almost say, regardless of expense; and its opening will at once place Liverpool in the very foremost rank of those cities which provide the machinery for a scientific engineering education. To all Liverpool engineers it will be a satisfaction to know that, under the able direction of Professor Hele Shaw, the engineering students of University College will commence this winter's session in their new school-house. Though the majority of us are now too old to go again to school, we shall rejoice to see the Lamp of Truth taken up by younger hands searching in new fields of discovery, and ever enlarging the domain of that profession whose proud boast it is, that it "directs the great sources of power in nature for the use and convenience of man."

During the summer a large party of American engineers visited Europe, and, as they made Liverpool their port of arrival, Liverpool engineers and their friends had the opportunity of showing their professional brethren from "over the water" some little attention and hospitality. As you know, the Mayor, E. H. Cookson, Esq., gave an official reception to the Americans, and entertained them with that hospitality which has always been a civic tradition of "the good old town." I have to congratulate you upon the position which your Society took in the local entertainment of our American friends, and I have reason to know that our attentions were highly appreciated by the visitors.

Allow me now to say a few words about our own affairs.

We are just entering on our Sixteenth Session, and may, I think, be fairly proud of our growth. My friend, the honorary secretary, has given me the following figures, which show the rapidity of our numerical progress. In 1880, after 5 years of the Society's existence, there were on the membership roll 3 honorary and 73 ordinary members. In 1885 these numbers had increased to 5 honorary and 99 ordinary members, and 6 students. At the time I write, we have 6 honorary members, 151 ordinary members, and 18 students; a rate of progress which, it appears to me, is eminently satisfactory. Our finances, I am glad to say, are also in a healthy condition. By our Accounts and Balance Sheet made up to 31st December, 1888, I see that, after paying all our lawful debts, we had a balance at the Bank of £136 1s. 10d. The investment of a portion of this money is

engaging the consideration of your Council, and I hope that, in accordance with the alliterative proverb that "money makes money," this modest nest egg will be the forerunner of others and of a handsome brood of chickens, which it will, perhaps, be time enough to count when they are hatched.

But while material prosperity makes matters comfortable for us, it ought not to be our chief concern.

As members of the Liverpool Engineering Society, our first object is to promote the study and practice of Engineering, and if we are not, according to our opportunities and abilities, contributing to this object, we have no business—I say it advisedly—we have no business to be members of this Society. By our membership we have accepted the duty of attending the Society's meetings as often as we conveniently can, and of contributing to the interest and value of the proceedings by taking an active part in the discussions, or by laying before our fellow-members the results of our individual experience in the special branch of engineering with which our daily duties make us most familiar.

For those of us whose engagements do not afford the necessary leisure for preparing formal papers, our rules provide that at every meeting there shall be an opportunity given of laying before the Society miscellaneous communications of professional interest. I suppose there are few of us who are not occasionally confronted by difficult engineering problems, the free discussion of which with our fellow-members would be of interest to them, and would also be a material assistance to ourselves in the practical solution of the particular difficulty we had encountered. I look on this rule as an exceedingly valuable feature of our Society, and one which, if duly used, will not only widen our experience, but will also do much to deepen our sympathy with one another,—a most desirable result, for we are not simply engineers, we are a *society* of engineers, and thus have a social as well as a professional relationship. We are bound together by a common interest, and by that *esprit de corps* which should know no jealousies, and which, in this relationship at least, should aim only at the common good.

The fortunes and misfortunes of business may, and will, often bring us into sharp competition with one another, but we may compete, and that keenly, and yet, in the serener atmosphere of a common devotion to a great science, be able to extend the right hand of fellowship to our hardest opponent in the struggles of life.

Forgive me if I appear to dwell somewhat upon this point of

encouraging, by all means in our power, a spirit of professional fraternity; for I feel that it is in this that we shall find the key to our Society's progress and usefulness. Let us be no niggards in communicating to one another those treasures of knowledge and experience with which all have been in some degree entrusted. In argument let us cherish a chivalrous regard for our opponents, and conduct our discussions with the frankness and candour which ever aim at truth rather than victory. Thus shall we best accomplish the main object of our association—the promotion and interchange of engineering knowledge and experience.

Whether we speak of the particular experience of the individual person, or of that wider, and ever growing, experience which is the rich inheritance of every age, we may alike define experience as knowledge gained from practice. In this sense engineering is, and always has been, eminently a science of experience—a science in which knowledge has been slowly built up by the tentative process of experiment,—not infrequently of trial and error,—in which both success and failure have played their part in perfecting the final result. Since the record of experience forms so important a part of our own Society's proceedings, it has occurred to me that it may perhaps be of interest, on this occasion, to submit to you some rambling notes of experiences in naval architecture, and of the use which the naval architect has made of those experiences by careful study and analysis.

In very early times, and amongst uncivilized peoples of the present day, we find that two distinct types of floating vessels have been in use for purposes of locomotion.

The one type is the canoe, hewn with infinite pains and labour from a single tree trunk; the other type is the coracle, with a frame of osier twigs, covered and made watertight by an outer skin laced to this basket-work foundation.

In the nature of the case, the first type was doomed from the beginning to ultimate extinction. Since size must always be limited by the dimensions of available trees, it left no room for expansion.

The second type, however, had in it, from the first, a germ of life. The difference, structurally, between the coracle of the ancient Briton and the Atlantic greyhound of his nineteenth century descendant is quantitative, not qualitative. It is a difference of degree, not of kind. There is a difference in size, in material, in method of propulsion, in development and completeness, but the same principle of construction runs through both. In both we have a transverse and

longitudinal framing so interlaced, or otherwise braced together, as mutually to assist each other in retaining the vessel's form; and this framework covered with an outer envelope, fulfilling the double duty of keeping out the water and of binding up the whole into a rigid structure. Thus, what probably originated in the compulsion of temporary environment, has been justified in principle by the experience of centuries.

We cannot but admit, however, that in respect of form the single-tree canoe, both in outline and modelling, is a more graceful work of art than the short, broad coracle, in which our woad-stained ancestors punted themselves across the sluggish stream, or the shallow mere.

In some branches of naval architecture excellence of form is almost as important a quality as structural sufficiency. Have we made much progress in this respect? I fear not. Indeed, it is almost a question if any radical progress is possible. In quite recent years we have had unearthed the buried galley of an old Viking captain. The form of this vessel has been conserved by Mother Earth, in an almost perfect state of preservation, for near a thousand years. Her lines have been carefully measured, and were reproduced in Volume XXII. of the "Transactions of the Institution of Naval Architects," where they may be studied by those who take an interest in such matters. Compare these lines with those of modern vessels designed specially for easy propulsion, and you cannot but be struck by the fact that the ancient Norse shipbuilder, conditioned as he was by requirements of duty, of size, and of capabilities of workmen, had as true an intuition of symmetry and due proportion as any of his successors in his art. No amount of investigation has yet revealed to us a form of least resistance; and now, as then, when once the ruling conditions have been satisfied, true design is dependent not so much upon formulated theories as upon that instinctive sense of beauty and fitness, which is characteristic of the artist rather than of the mathematician, and which is the exclusive possession of no age and no place. For the present we must be content, in this respect, to be as good as, but no better than, our fathers.

I must not detain you by detailed description of this remarkable vessel; the more so because it has already been so completely done by Mr. Archer in the paper to which I have already referred. There is, however, one structural feature, rendered possible by the comparatively small size of the vessel, in which the Viking's ship has distinctly the advantage over larger and more modern wooden

vessels. In the coracle, we saw the tightly-stretched outer skin binding together and securing the frame-work against undue movement in any direction. In the Norse ship this end was attained by the outer planks being worked to overlap one another at their edges, in clinker fashion, the edges being substantially rivetted together, and further secured to the frame-work, so that each part helped to support the whole. In an ordinary wooden ship with thick outer planking, there is a distinct retrogression from this principle. Edge union between the planks is, for the most part, conspicuous by its absence, and in this, appears to me, to lie the inherent weakness of wooden vessels. It is this difficulty of securing efficient union between the parts that sounded the death knell of "the wooden walls of Old England" as soon as ships of large dimensions, and therefore subject to severe strains, came into demand for war or commerce.

Naturally, when iron was first used for shipbuilding, the size and proportions of iron vessels remained pretty nearly the same as those then current for wooden ships, and this fact, with the superior strength of the material and of its structural connections,—even with moderate scantlings,—lent immense strength to the earliest iron vessels; while their relative lightness gave them cargo carrying ability which made them profitable investments for shipowners, and thus, led to the rapid adoption of the new material.

But these moderate proportions were not to rule for long.

With characteristic felicity of illustration, Mr. Scott Russell once called the middle body of a ship, "the ship's breeches pocket." So eminently practical a class of men as British shipowners were not likely to be long in finding out that the larger this part of a ship could be made, the more profitable she would be. Existing iron ships were lengthened, and gradually new ones came to be built, of proportions very different from those in vogue when the earliest iron vessels earned their reputation for great strength.

It was my lot, between 30 and 40 years ago, to be engaged on the repair of an iron steamer that had broken down in a seaway from longitudinal weakness. Probably this was one of the earliest recorded instances of the kind. The ship was torn down amidships, through the bulwark, the stringer and sheer strake, the strake next below the sheer strake, and through the upper edge of the strake next below that, into the opening through the ship's side for the hot-well discharge.

The registered dimensions of this vessel were, 242 feet in length, by 30 feet in breadth and 20 feet depth of hold. Although I was

too young at the time to have any say in the matter, and could only do what I was bid, the incident made a great impression on me, and I have dwelt somewhat upon it because I have since had the opportunity of reading the official report of the very experienced surveyor who examined this steamer, in which report the following remarkable words occur :—" Since the breaking down of this vessel, there has been a general impression that a limit is reached with respect to length in screw vessels." It is only fair to the writer of this report to assume that he meant by these words, relative, not absolute length; for there were in existence at the time, several screw steamers of, and over, 300 feet in length. But even with this modification, his generalization was too hasty and too sweeping. A more careful study of the facts of the case, in the light of the theory of beams, would have revealed the cause of this vessel's weakness, and would have shown that with a better distribution of material, and due care and attention to details, she might have been made perfectly seaworthy, even with greater length; and that, too, with less weight of iron than was actually used in her construction.

After this experience, several steamers were strengthened, and the knowledge thus gained was made the basis of many important improvements in the scantlings and structural arrangements of iron ships.

Important as longitudinal strains are, there are other sea strains which are hardly less important, and which, if not adequately provided against, may be the cause of serious loss and inconvenience, if not of actual danger. One, not infrequently, meets with practical proof that some of the details of construction, as ordinarily carried out, are still insufficient to resist the severe racking strains to which ships are subjected by violent pitching and rolling at sea. The tendency of a vessel under these conditions to alter her transverse form, brings most trying strains upon the rivetting of the parts whose function it is to resist this action. The remedy is manifestly to be found in increasing the rivet power at such places, and in paying special attention to the quality of workmanship. The beam arms, stiffening web-frames, and the bulkheads I have usually found to be the places where the straining manifests itself, and where, consequently, special attention needs to be paid to the rivetting connection.

The terrible disaster of capsising at sea, in face of which all a seaman's courage and resource are helpless and unavailing, has in all times claimed so many victims, that it can hardly be wondered at if

designers have sometimes erred on the side of excessive stability. If, with a vessel having extreme natural stability, the arrangement of cargo is such as to still further lower the centre of gravity, and if, in that condition, the ship meets with heavy weather at sea, we must expect her to be uneasy and laboursome, with the certain result that the racking and straining of the structure will test the rivetted work to the utmost. That this, however, is a lesser evil than the fatal danger of instability, will be readily conceded by all.

While I am fully alive to the exigencies of modern ship loading, where the heterogeneous character of the cargo and the unsuitable order of its arrival alongside make design in its stowage almost impracticable, I am, nevertheless, of opinion that a little less haste sometimes might, even from a "breeches pocket" point of view, be found beneficial, and that occasional experimental tests of the position of the centre of gravity, by inclining the ship *after loading*, and subsequently collating the results with the ship's behaviour at sea, would yield to the owner both interesting and profitable information. In this way, practical knowledge would be accumulated in exact quantitative terms—a quality in which practical knowledge is too apt to be deficient. Such knowledge would be of the greatest service to the designer, for almost nothing is now known, with accuracy, of the ordinary metacentric heights with which the various types of merchant vessels proceed to sea.

The principles which govern the stability of floating bodies have long been known, but not until recent years have they been much studied and applied by those practically concerned in the construction and handling of merchant ships. This state of things is now vastly improved. The effect of this improvement is distinctly traceable in the reduced number of unexplained losses at sea.

In the case of passenger steamers, the proportion of space available for cargo is such, that its influence on stability can generally be kept under control, and the happy mean between excessive stability on the one hand, and undue tenderness on the other, can, to the great comfort of the passengers, be practically secured.

The pressure of modern competition has been felt as keenly by shipowners as by other classes of the community; but, sharp as the lessons of this experience have been, they have not been an unmixed evil. They have led to improvements and economies which must have been beneficial both to shipowners and to society at large. The managing owner of an important line of steamers told me, recently, that shipowners were now living upon what, a few years ago, they

were throwing away as valueless. In other words, that, as compared with old times, they were living on economies rather than on profits.

Under the pressure of this experience, there has been a constant and urgent demand to increase the *paying load* of cargo steamers. This demand has been answered in at least three different ways:—

By increasing the ratio of the immersed to the unimmersed portion of the ship.

By decreasing the weight of the ship herself.

By reducing the ratio of the fuel used to the cargo carried.

Deeper loading being the simplest and easiest method of increasing the paying load, was naturally the first solution of the problem to be adopted; and where it could be shown that a vessel was carrying a lighter load than she might carry with safety to ship, crew, and cargo, it was manifestly legitimate to load the ship deeper, and so earn a larger freight. But in the days when Government interference in the matter of loading was unknown, and when there was no educated public opinion to influence private action in this matter, deeper loading was pushed to a dangerous extreme, and disaster was not infrequently the natural consequence. More than a quarter of a century ago, I remember the colloquial expression at one of our East Coast ports, "They might have washed their hands at the scuppers," as descriptive of the deeply-laden condition in which steamers had gone down the river, outward bound.

We all know the history of the agitation on this subject, inaugurated by Mr. Plimsoll, and which culminated in the settlement of the matter, for the present at least, through the labours of the Load-line Committee. Admiring, as I do, the patience, the energy, and the skill with which that Committee grappled with the difficulties of this problem, I would be the last to cavil at the settlement which they have made. At the same time, I cannot lose sight of the fact that, whether for good or evil, they have sanctioned and have practically made universal a depth of loading which, for some types of vessels, the best class of shipowners, before the agitation commenced, would have characterised as both greedy and dangerous. However much the construction of ships in the future may be improved by strengthening and protecting the vulnerable parts upon and above deck, I venture to think that increasing the ratio of the immersed to the unimmersed portion of the ship cannot with safety go much further than it has already gone.

If kept within the limits of safe experience, a more legitimate, and certainly a more scientific method of increasing the paying load is by

reducing the weight of the ship herself. This course has, in the past, yielded very substantial results. Taught by experience, the naval architect has learned so to use his material, that while the strength and sufficiency of the structure has been maintained, and even improved, its weight has been substantially reduced.

In the earliest iron ships the value of the thorough union of the various parts of the outer skin to one another, and to the frame, appears to have been overlooked; in short, the builders seem to have had scant faith in the thin iron skin, so that they not only made it generally thicker than was necessary, but they loaded the ship with heavy and closely spaced internal frames to give the skin support.

If we bear in mind the thick outer planking, and the large, closely spaced timbers of the wooden ships, which were the only vessels that early iron shipbuilders were familiar with, we cannot wonder at their hesitation to trust thin iron plates to replace thick oaken planks. On the contrary, we must admire the boldness and courage of these early workers, in what was practically a new art, in going as far as they did; but still, these heavily framed and heavily plated vessels gave scope and margin for reductions of direct weight of considerable magnitude.

When cases of longitudinal weakness, such as those I have already referred to, arose, it was further seen that the distribution of material was at fault. It was seen that if there was failure, it was near the middle and not at at the ends of the ship; and a more scientific distribution of the iron was thus suggested, ultimately leading, by gradual steps, to a lighter construction, and with such increased strength that it became practicable to build seaworthy vessels of much more profitable proportions.

While this re-arrangement of material was going on, steel entered the field. By its superior strength and toughness—as I have shown in a paper which I recently had the honour of reading before this Society—it has further reduced the structural weights of modern cargo steamers. The careful study and analysis of the structural arrangements of even these vessels, aided by the light of experience of their working, may yet show us how further economy of weight may be secured.

Difficult and impracticable as it is to assign quantitative values to the sea strains brought upon vessels and their various parts, it *is* practicable, when cases of failure come under our notice, to study the conditions and underlying principles concerned in those failures.

By carefully correlating failures and successes under similar conditions, we may build up, within narrow limits, a scheme of right proportions for the structural arrangements of other vessels.

Something has been done in the past, and may still be done in the future by so arranging, what have been called, the incidental or domestic features of the ship that any one element of the structure shall fulfil several functions, and thus lend either local or general strength to the whole, with a minimum of material. A difficulty in carrying out such a scheme of scantling arrangements as this, lies in the fact that classification in Lloyd's Register is a commercial necessity for most merchant vessels; and that Lloyd's Rules, based on a particular system of construction, lay down specific sizes for the various parts, which sizes must, in the main, be adhered to irrespective of strength given to the structure in other ways. I know, and can sympathise with, the delicate position in which the authorities of Lloyd's are placed in this matter; but it must be admitted that a system of classification, based upon tables of scantling and not upon general merits, tends to stereotype arrangements which may, or may not, be the best practicable under the circumstances of each particular case,—and thus, individual judgment and invention are discouraged.

Reduction in weight of propelling machinery has never been a very important quantity. The improvements which have taken place in this department have been addressed primarily to economy of fuel, to improvements in working, and to reduction of first cost rather than to economy of weight. In the gradual changes which have taken place, the cumbrous side-lever and geared engines have given way to simpler direct acting engines, but the saving of weight by these radical changes has been masked by the addition of surface condensers, heavier boilers, and by a multitude of auxiliary engines for purposes which the increasing size of ships and machinery has rendered necessary.

The Admiralty have, for some time, been moving in the direction of securing a reduced weight of machinery on a given maximum horse-power by adopting forced draught and high piston speeds, and by using the braced wrought-iron framing, introduced, I believe, by Dr. Kirk in the engines he made for H.M.S. "Nelson." The necessity of keeping the sea and of maintaining full power for many days in succession, with a limited engine-room staff, and with comparatively short opportunity in port for the examination and overhaul of machinery, have, hitherto, prevented the adoption of these changes to any important extent in the Mercantile Marine.

Fortunately, it is not my province to-night to indulge much in prophecy, but I venture to think that if there is to be, in the near future, any material reduction of weight in the propelling machinery of merchant steam vessels, it must be accomplished mainly by the use of forced draught. It appears to me that this will allow a much closer approximation to the practice of locomotive engineers, who, by the use of artificial draught, have succeeded in efficiently burning a large quantity of fuel on a small grate; and who by utilising the heat so generated in long tubes of small diameter, have been enabled to get a large amount of heating surface into a shell of small diameter, thus producing a light and efficient boiler.

The engine power, however, in ordinary merchant cargo steamers, is so moderate that the weight of machinery forms too unimportant a proportion of the gross load displacement for it to be worth while to sacrifice other advantages for the sake of a comparatively small saving in the weight of the engines and boilers themselves; and in the case of passenger steamers, many other complex conditions intervene to the same result. The naval architect therefore—and in this term I include the marine engineer, for they are one and the same—has addressed his attention in the engine-room department to reducing the ratio between the fuel used and the cargo carried. Although this appears an indirect method of reducing the ship's weight, it has been a most efficient one.

Economy of fuel not only effects the saving of the cost of the coal itself, and of loading it into the ship's bunkers, but it also releases the space and displacement it would have occupied, to be used by freight paying cargo. This is a most important feature. The great size of the steamer "Great Eastern" was mainly due to the large quantity of coal that it was necessary, at that time, to provide for a vessel of her intended speed making an Eastern voyage. The consumption of coal per indicated horse-power in 1850 to '55 was, as nearly as may be, three times what it is now, and this change has rendered it possible, not to say profitable, to employ steamers on voyages which could not have been attempted by steam at all, 35 years ago. You all know well the steps by which these changes and economies have been brought about. Their conception has been mainly due to the studies and researches of the scientific engineer; and, however necessary it may have been for him to arm himself with practical knowledge and experience, or to associate himself with those possessing these qualities, the exponent of theory, in this instance, has abundantly justified his claim to be heard.

But beyond the direct economy of fuel in the *manufacture*, so to speak, of power, experience and investigation have enabled us to make most substantial savings in the *application* of that power.

At one time the typical cargo steamer was a small boat with large engines, now it is a big boat with small engines.

Whether the biggest ship always makes the most money for the shipowner, is a question which he must answer for himself—it turns on a number of commercial conditions with which we have no concern; but all experience goes to show that so far as the mere carrying is concerned, and other things being equal, the most economical carrier is the biggest ship. This is, no doubt, due partly to the fact that numbers of incidental charges do not increase in proportion to the size of the vessel. But apart from all these commercial economies, there remains the undoubted mechanical fact that a big ship is, relatively, more easily driven than a little one, so that, by simple increase of size, substantial reduction can be made in the ratio of fuel used to cargo carried.

Though experience has shown that this is so, the exact nature and extent of the economy thus to be gained was never thoroughly understood until the law which governs the relative resistance of two similar vessels of different size, was clearly grasped. Mr. Mansel has pointed out that this law was long since specifically stated by M. Reech; but it was little known to, and had less influence with, practical men until it was established and emphasised by the elaborate experiments and researches of the late Mr. Froude.

Mr. Froude's law of comparison may be thus stated. In two similar vessels of different lineal dimensions, the resistances of those vessels will vary as the cube of a lineal dimension, when the speeds of the vessels are to one another, as the square root of the ratio of the dimensions.

Stating this law in symbols and writing l, for the length of the typical vessel—or for any other dimension, for as the two vessels are similar, all dimensions have the same ratio to one another; v, for the speed of the typical vessel; r, for the resistance of the typical vessel at the speed v; L, for the length of the vessel to be compared with the type ship; V, for the speed of the compared ship; R, for the resistance of the compared ship at the speed V; we shall have by Mr. Froude's law of comparison:—

$$\frac{R}{r} = \frac{L^3}{l^3} \text{ when } \frac{V}{v} = \sqrt{\frac{L}{l}}.$$

This resistance, multiplied by the speed at which the resistance is

overcome, will manifestly give us the power necessary to drive the ship at that speed; but on one assumption, and that a very large assumption, that the power exerted is doing nothing else but driving the ship; which is very far, indeed, from being the case, even with the best regulated machinery.

In ordinary cases the machinery of a cargo steamer, in addition to propelling the vessel through the water, is feeding the boilers against their working pressure of steam; is driving the air and circulating pumps upon which the vacuum in the condenser are dependent; may be sometimes working bilge pumps; is overcoming the friction of its own working parts, and also the friction on those parts which is due to the external load on the engines:—and even after the residue of power, whatever it may be, is delivered to the propeller, a considerable portion of it is dissipated in communicating motion to the water which is not propulsive in its effects, but may perhaps even be the contrary.

Again, we know that of the steam generated in the boiler an important part is always wasted, or at any rate not used in the production of power in the cylinders. And again, of the theoretical units of heat which should be liberated by the combustion of the coal in the furnaces, how much is wasted and allowed to escape without yielding its burden of power to the machine it was intended to feed? In the unravelling of all this terribly tangled skein there is abundant scope for observers and investigators.

The analysis of steamship performances, either after the methods of Mr. Froude, or those adopted by Mr. Mansel, and so clearly explained to us by Mr. Walter Sang in his paper of last session, cannot fail to bring to light much useful information and help to draw out, thrum by thrum, the threads of this tangled mass.

An admirable example of experimental observations, carried out at sea under conditions, as nearly as possible those of ordinary sea work, is recorded in the last issue of the "Proceedings of the Institution of Mechanical Engineers." We want many such experiments, the record and analysis of which would be most useful in clearing up points which at present are obscure.

We have seen how we may pass from one size of vessel to another—How are we to pass from one form of vessel to another?

The forms of ships are infinite in their variety, and are not devised according to the formulæ of any of the regular mathematical solids. Is it possible, then, to reduce these various forms to one common denominator, and by means thereof to compare them with one another?

No attempt in this direction has, as yet, met with the general favour which Dr. Kirk's block model analysis has secured. To those of my hearers who are not familiar with this ingenious device, I should perhaps say that Dr. Kirk's plan is to compare vessels by imagining them to be reduced to a common form, having a parallel middle body of rectangular section, with two wedge-shaped ends also of rectangular cross section. This block model, as it is termed, is so arranged that it shall have the same draught, the same area of cross-midship section, the same length, and the same displacement as the ship of which it is the prototype. By a very simple and ingenious piece of arithmetic, a block model fulfilling these conditions can be calculated in a very few minutes.

Dr. Kirk calculates the wetted surface and the mean angle of entrance and run of such an ideal block model, and these are a sufficient approximation to the corresponding elements in the actual ship to enable comparisons to be established with known vessels, and preliminary calculations to be made.

Used as Dr. Kirk proposes to use such a model, and with the limitations he applies to it, it is very serviceable in the early stages of a design; but inasmuch as it is possible to have the same calculated block for ships of very different proportions, this method hardly lends itself to comparison of widely differing types.

Mr. Froude's investigations into the law, which enabled the performance of one vessel to be correlated with that of another of similar form, but differing in size, were undertaken with the view of predicating the resistance of a full sized vessel from the measured resistance of her scale model. One great value, therefore, of his law of comparison is that, by means of it and experimental investigation, we are enabled to appraise the effect of form.

Mr. Froude's theoretical and experimental enquiries have established for us the nature of the principal resistances which a vessel offers to being driven through the water. I have no intention of detaining you this evening with a full consideration of this subject, but there is one result of these investigations to which I must refer, because it has had a very remarkable result in the development of cargo steamers. Mr. Froude found that the resistance of vessels at low speeds consisted principally of skin friction, and that, at such speeds, wave-making resistances and other water disturbances, were comparatively unimportant. In other words, that those elements of resistance which are dependant upon the vessel's form (providing it is decently fair), are practically immaterial, while those which depend

upon the extent of wetted surface are of the first importance. At high speeds these conditions are very different and may even be reversed, but this is too large a subject to be entered upon now. It is perhaps enough to say that high speed and low speed, are relative terms, and that a high speed for one vessel is not necessarily a high speed for a vessel double her size.

The analysis of practical experience has confirmed the result of Mr. Froude's enquiries; and when these ideas were mastered a class of steamers sprang rapidly into existence, which have revolutionized the carrying trade wherever there are large quantities of goods to be transported. These vessels are of steel, and are thus light in structural weight; they have triple expansion engines, and thus take advantage of the most recent developments in marine engineering to reduce their fuel load; they are of large dimensions, and by reason of their size they are relatively easily propelled; they are of full form, in virtue of which they are proportionately large carriers without unduly increasing their resistance at the speeds for which they are intended.

In olden times ships were only used for the transport of precious goods and luxuries of which large values would lie in small compass; thus ships of moderate capacity were then sufficient for all the purposes of the merchant, but now our ships are carrying the daily food, fuel and clothing for millions of people, and the materials for every manufacture of the world, and are correspondingly increased in size.

One cargo vessel of the most modern type, I have in my mind as I write, which is capable of carrying considerably over 6,000 tons of weight, and of steaming an average of 10 knots at sea, while burning well within 30 tons of coal a day. An idea of her capacity may be gained from this:—Her out-turn of weight, if loaded into ordinary railway trucks, measuring about 18 feet over the buffers, would require for its removal a train nearly three miles long.

A record in the Church of St. Mary Redcliffe, at Bristol, gives the names of the fleet of vessels belonging to the founder of that Church, William Canings, Priest, Deane, Merchant, and Mayor of Bristol, and probably one of the largest if not the largest shipowner in this country in the reign of Edward the Fourth. The list quotes 10 ships of an aggregate tonnage of 5,672 tons;—for the times this was indeed a goodly array. Compare it with the fleet to-day of the Peninsular and Oriental Steam Navigation Company—51 steam vessels of an aggregate gross tonnage of 198,051 tons.

These changes have been the slow work of four centuries. Much of it, perhaps, the painful copying of precedent without originality and almost without life; till the art of the craftsman had well nigh perished. The mere accumulation of the dry facts of experience does little by itself to further the progress of either science or art. It is not until accurate observation of practical facts is wedded to careful study and analysis of those facts by the light of natural laws, that the full riches of experience can be developed, or its valuable lessons applied to new problems.

The art of accurate observation; the power of grasping the significant features of phenomena; the frame of mind which perceives the underlying natural law, are all matters of education. With such a School of Technology in our midst as that, the opening of which we shall so soon celebrate, what amazing possibilities of engineering advancement open up their long vistas before us. We have seen something of what four centuries of the past have done, who shall say what four centuries of the future shall do? The world is still young.

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